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[0001] RAKE-BASED CDMA RECEIVERS FOR MULTIPLE RECEIVER ANTENNAS

[0002] CROSS REFERENCE TO RELATED APPLICATIONS

[0003] This application claims priority from U.S. provisional application serial No. 60/507,874, filed September 30, 2003, which is incorporated by reference as if fully set forth.

[0004] FIELD OF THE INVENTION

[0005] The present invention relates to the field of wireless communications. More specifically, the present invention relates to a code division multiple access (CDMA) receiver.

[0006] BACKGROUND

[0007] A received CDMA signal , $r_l(t)$, at l^{th} $(l \leq L)$ receiver antenna element out of an L element array is denoted as per Equation 1:

$$r_l(t) = \sum_{k=1}^{K} \sum_{n=-\infty}^{\infty} \sum_{m=1}^{M} A_k s_{k,n} p_k(t - nT - \tau_{k,m}) h_{k,m,l}(t) + n(t) \qquad \text{Equation 1}$$

where A_k is the signal amplitude of k^{th} user, $s_{k,n}$ is the n^{th} symbol of k^{th} user, $p_k(t)$ is the signature waveform, including the spread code and pulse shaping waveform, of k^{th} user. $h_{k,m,l}(t)$ is the channel response of m^{th} path from l^{th} antenna of k^{th} user. $n(t)$ is the combined interference which is typically due to the interference from other cells and additive channel noise. As is typical, this interference has the statistics of white Gaussian noise. The n^{th} symbol of the k^{th} user is of interest and the user index k and the symbol index n are dropped. After despreading the received signal for the k^{th} user and n^{th} symbol and for all M paths and all L antennas, Equation 2 is derived as follows:

$$d_{m,l} = Ah_{m,l}s + z_{m,l} \qquad \text{Equation 2}$$

where $z_{m,l}$ is the residual signal at the despreader for mth path and l^{th} receiver antenna.

[0008] It is traditionally and commonly assumed that all $z_{m,l}$ $(1 \le m \le M, 1 \le l \le L)$ are Gaussian variables, and they are mutually uncorrelated across different multipath components and across different antennas. This assumption leads to a very simple and traditional receiver called a "Rake receiver" as shown in Figure 1, where each Rake, or each branch in Figure 1, estimates the complex channel weight gain (CWG) independently. As shown in Figure 1, the antenna array has L elements, 110_1 to 110_L. For each element 110, a group of delays 112_{11} to 112_{LN}, produce a group of delayed versions of the vector received by that element 110. Each delayed version is despread by a respective despreader 115_{11} to 115_{LN}. Each despread output is input into a respective CWG generation circuit 105_{11} to 105_{LN}. The derived CWGs are respectively applied to each despread output via respective multipliers 120_{11} to 120_{LN}. The weighted outputs are combined by a combiner 125. The combiner 125 usually uses the maximum-ratio combining (MRC) in order to achieve the maximum signal-to-noise ratio at the combiner output. Mathematically, each Rake receiver estimates the channel gain $g_{m,l}$, where $g_{m,l}$ is an estimate of $Ah_{m,l}$, and noise variance $\sigma^2_{m,l}$, where $\sigma^2_{m,l}$ is an estimate of the power of $z_{m,l}$). If MRC is used, the combiner generates $\sum_{\substack{1 \le m \le M \\ 1 \le l \le L}} \frac{d_{m,l} g^*_{m,l}}{\sigma^2_{m,l}}$. Since $g_{m,l}$ is an estimate of $Ah_{m,l}$ and $\sigma^2_{m,l}$ is an estimate of the power of $z_{m,l}$, the generation of $g_{m,l}$ for any one particular Rake receiver is independent of all other Rake receivers. This approach assumes that all $z_{m,l}$ $(1 \le m \le \mathrm{M}, 1 \le l \le L)$ are zero mean Guassian variables, which are mutually uncorrelated across different multipath components and accross different antennas. However, there is correlation across the multipath components and antennas, which result in inter symbol interference (ISI).

Also, due to correlation between multiple user also over the multipath components and antennas, multiple access interference (MAI) is also increased. Accordingly, the receiver performance is degraded.

[0009] Accordingly, it is desirable to have alternate receiver configurations.

[0010] SUMMARY

[0011] A receiver comprises a plurality of antenna elements for receiving a data signal. Each antenna element has a plurality of Rake fingers. Each Rake finger processes a received multipath component of the received data signal of its antenna element by applying a complex weight gain to that received multipath component. A complex weight gain generator determines the complex weight gain for each Rake finger for each antenna element using an input from all the Rake fingers. A summer combines an output of each Rake finger to produce an estimate of the data signal.

[0012] BRIEF DESCRIPTION OF THE DRAWINGS

[0013] A more detailed understanding of the invention may be had from the following description, given by way of example and to be understood in conjunction with the accompanying drawings wherein:

[0014] Figure 1 is a prior art Rake receiver;

[0015] Figure 2 is a block diagram of a Rake-based receiver with two receiver antennas operating in accordance with the present invention;

[0016] Figure 3 is a block diagram of a CWG generation device used in conjunction with the receiver of Figure 2;

[0017] Figure 4 is a block diagram of a circuit used to implement $\boldsymbol{R}$ estimation in conjunction with the receiver of Figure 2;

[0018] Figure 5 compares the block error rate (BLER) at 50km/hr between a conventional Rake receiver and the Rake receiver of Figure 2; and

[0019] Figure 6 compares the BLER at 120km/hr between a conventional Rake receiver and the Rake receiver of Figure 2.

[0020] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] The preferred embodiments will be described with reference to the drawing figures where like numerals represent like elements throughout. Hereafter, a wireless transmit/receive unit (WTRU) includes, but is not limited, to a user equipment, a mobile station, a fixed or mobile subscriber unit, a pager, or any other type of device capable of operating in a wireless environment. When referred to hereafter, a base station includes, but is not limited to, a base station, a Node-B, a site controller, an access point, or any other interfacing device in a wireless environment. The multiple antenna element Rake receiver can be used in a WTRU, base station or both.

[0022] Using L receiver antenna elements, all Rake finger outputs are organized into groups having the same de-spread symbol into the same vector. Each Rake finger output is denoted as vector $\boldsymbol{d} = [d_{1,1}, d_{1,2}, \ldots, d_{1,L}, d_{2,1}, d_{2,2}, \ldots, d_{M,1}, d_{M,2}, \ldots, d_{M,L}]^T$. Similarly, the noise vector at each Rake finger output is denoted as $\boldsymbol{z} = [z_{1,1}, z_{1,2}, \ldots, z_{1,L}, z_{2,1}, z_{2,2}, \ldots, z_{M,1}, z_{M,2}, \ldots, z_{M,L}]^T$, and the channel vector for all Rake fingers are denoted as. $\boldsymbol{h} = [h_{1,1}, h_{1,2}, \ldots, h_{1,L}, h_{2,1}, h_{2,2}, \ldots, h_{M,1}, h_{M,2}, \ldots, h_{M,L}]^T$. Thus, Equation 3 is derived as follows:

$$\boldsymbol{d} = A\boldsymbol{h}S + z \qquad \text{Equation 3}$$

[0023] The noise correlation matrix is derived as per Equation 4:

$$\boldsymbol{R} = E(\boldsymbol{zz}^H) = E(\boldsymbol{dd}^H) - A^2E|s|^2\boldsymbol{hh}^H \qquad \text{Equation 4}$$

[0024] where for binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) modulation, $E|s|^2 = 1$, and Equation 4 is further simplified as per Equation 5:

$$\boldsymbol{R} = E(\boldsymbol{zz}^H) = E(\boldsymbol{dd}^H) - A^2\boldsymbol{hh}^H \qquad \text{Equation 5}$$

[0025] An optimal receiver in terms of maximizing the log-likelihood function provides the data detection as denoted as per Equation 6:

$$v = (\boldsymbol{R}^{-1}\boldsymbol{h})^H\boldsymbol{d} \qquad \text{Equation 6}$$

[0026] Figure 2 is a block diagram of a Rake-based element 200 using a CWG generation device 205 in conjunction with L receiver antenna elements 210_1 to 210_L. The components of Figure 2 can be implemented on a single integrated circuit (IC), multiple ICs, discrete components or combination of integrated circuits and discrete components. For each element 210, a group of delays 212_{11} to 212_{LN}, produce a group of delayed versions of the vector received by that element 210. Each delayed version is despread by a respective despreader 215_{11} to 215_{LN}. All despreader outputs from the L antenna elements 210 for all multipaths are fed to a complex weight gain (CWG) generation device 205 (see Figure 3), within which a channel estimation $\boldsymbol{h}$ is calculated 320, correlation matrix $\boldsymbol{R}$ is calculated 305 based on the data from all of the despreaders 215 and the channel estimation $\boldsymbol{h}$, the inverse of $\boldsymbol{R}$ is calculated 310, and then the weight is calculated as $(\boldsymbol{R}^{-1}\boldsymbol{h})^H$ 315. Each element of the calculated $(\boldsymbol{R}^{-1}\boldsymbol{h})$ is applied as a CWG at each multiplier 220_{11} to 220_{LN} of each Rake finger. These weighted components are summed by a summer 225 to produce soft symbols. Accordingly, the CWG generated for any one Rake finger is derived from all of the despreaders 215.

[0027] Since the correlation matrix $\boldsymbol{R}$ considers each path for each antenna element, the complex weighting corrects for the ISI. Additionally, since this correction is also applied to other user signals, MAI is also suppressed to some extent across the antennas and paths.

[0028] The noise correlation matrix can be estimated, $\boldsymbol{R}$, as per Equation 7:

$$\hat{\boldsymbol{R}} = \frac{1}{N}\sum_{k=1}^{N}\boldsymbol{d}(\mathrm{k})\boldsymbol{d}(\mathrm{k})^H - \frac{1}{N}\sum_{k=1}^{N}\hat{\boldsymbol{h}}(\mathrm{k})\hat{\boldsymbol{h}}(\mathrm{k})^H \qquad \text{Equation 7}$$

where $\boldsymbol{d}(\mathrm{k})$ is the vector $\boldsymbol{d}$ for a k^{th} symbol, $\hat{\boldsymbol{h}}(\mathrm{k})$ is the channel estimation (which is also an estimate of vector $A\boldsymbol{h}$) for a k^{th} symbol, N is the estimation length in symbols.

[0029] In Figure 4, an embodiment of the $\boldsymbol{R}$ matrix estimation 305 is shown. The channel estimation $\boldsymbol{h}$ is vector multiplied 400 by its complex conjugate transpose (Hermetian), producing $\boldsymbol{h}(k)\boldsymbol{h}(k)^{\mathrm{H}}$. The multiplied results are averaged 405,

$\frac{1}{N}\sum_{K=1}^{N} \boldsymbol{h}(k)\boldsymbol{h}(k)^H$. The data from each despreader 215 is vector multiplied 410 by its Hermetian, producing $\boldsymbol{d}(k)\boldsymbol{d}(k)^H$. The results are averaged 415, $\frac{1}{N}\sum_{k=1}^{N} \boldsymbol{d}(k)\boldsymbol{d}(k)^H$. A matrix subtraction 420 of the averaged channel estimate from the averaged data is performed, producing $\hat{\boldsymbol{R}}$ as per Equation 7. Figure 5 compares simulation results between a conventional Rake receiver and a Rake-based receiver using an International Telecommunications Union (ITU) voice activity factor (VA) channel model operating in accordance with the present invention at a vehicular speed of 50km/hr. Figure 6 compares simulation results between the conventional Rake receiver and the Rake-based receiver using an ITU VA channel model operating in accordance with the present invention at a vehicular speed of 120km/hr. The simulations compare the performance of a traditional Rake with one antenna element "$Rake(1RxAnt)$", two correlated antenna elements "$\mathrm{RakeReceiver(2RxAnt-cor)}$", two uncorrelated antenna elements and "$\mathrm{RakeReceiver(2RxAnt-uncor)}$" to an uncorrelated embodiment of the present invention "$\mathrm{NewReceiver(2RxAnt-uncor)}$" and a correlate embodiment "$New\mathrm{Re}ceiver(2RxAnt-cor)$". In each case, the receiver operating in accordance with the present invention provides much better performance than the conventional Rake receiver.

[0030] While the present invention has been described in terms of the preferred embodiment, other variations which are within the scope of the invention as outlined in the claims below will be apparent to those skilled in the art.

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